CHAPTER 3. EXPLOSIVES AND THEIR PROPERTIES[1]

3-1. Explanation. A chemical explosive is a compound or a mixture of compounds which, when subjected to heat, impact, friction, or shock, undergoes very rapid, self-propagating, heat-producing decomposition. This decomposition produces gases that exert tremendous pressures as they expand at the high temperature of the reaction. The work done by an explosive depends primarily on the amount of heat given off during the explosion. The term detonation indicates that the reaction is moving through the explosive faster than the speed of sound in the unreacted explosive; whereas, deflagration indicates a slower reaction (rapid burning). A high explosive will detonate; a low explosive will deflagrate. All commercial explosives except black powder are high explosives.

3-2. Properties of Explosives. Important properties of explosives are weight strength, cartridge strength, detonation velocity, density, detonation pressure, water resistance, and fume class. For each explosive these properties will vary with the manufacturer and his methods of measurement.

a. Strength.

(1) Strength has been traditionally used to describe various grades of explosives, although it is not a true measure of ability to perform work and is therefore misleading. Because the term is so common in the industry, however, inspectors and other CE personnel should have some knowledge of the basis of strength ratings.

(2) The two common ratings are "weight strength," which compares explosives on a weight basis, and "cartridge strength" (bulk strength), which compares explosives on a volume basis. Strengths are commonly expressed as a percentage, with straight nitroglycerin dynamite taken as the standard for both weight and cartridge strength. For example, 1 lb of extra dynamite with a 40 percent weight strength, 1 lb of ammonia gelatin with a 40 percent weight strength, and 1 lb of straight dynamite with a 40 percent weight strength are considered equivalent. One 1-1/4- by 8-in. cartridge of extra dynamite with a 30 percent cartridge strength, one 1-1/4- by 8-in. cartridge of semi-gelatin with a 30 percent cartridge strength, and one 1-1/4- by 8-in. cartridge of straight dynamite with a 30 percent cartridge strength are equivalent. Fig. 3-1 illustrates a variety of dynamite cartridge sizes.

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[1] This section is largely a condensation of U. S. Bureau of Mines Information Circular 8405 by R. A. Dick.[6]

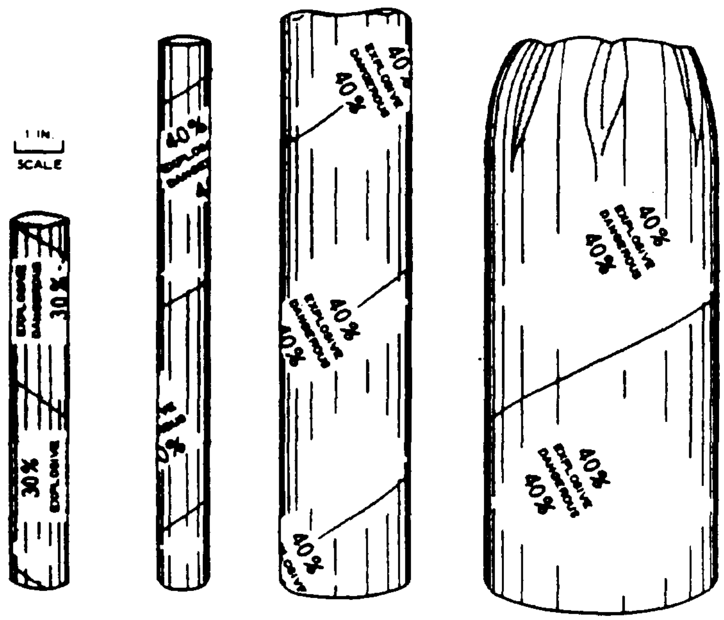

Fig. 3-1. Common sizes of dynamite cartridges

(3) The term strength was first applied when dynamite was a mixture of nitroglycerin and inert filler, such as kieselguhr (diatomite). Then 60 percent dynamite contained 60 percent nitroglycerin by weight and was three times as strong as a 20 percent dynamite. Straight dynamites today contain such active ingredients as sodium nitrate and carbonaceous material in place of inert filler. Consequently, a 60 percent straight dynamite, which contains 60 percent nitroglycerin by weight is only about 1.5 times as strong, because of the energy supplied by the additional active ingredients in the 20 percent grade. Furthermore, 60 percent weight strength straight dynamite and 60 percent weight strength extra dynamite will produce different results due to a difference in detonation velocity.

(4) Normally the cartridge count, i.e. the number of cartridges in a 50-lb box, and one of the strength ratings can be obtained for an explosive. A nomograph relating the two strength ratings is given in Fig. 3-2. The cartridge count is roughly 140 divided by the specific gravity. If a line is drawn through the cartridge count and the given strength rating, the unknown strength can be read where this line intersects the scale of the unknown strength.

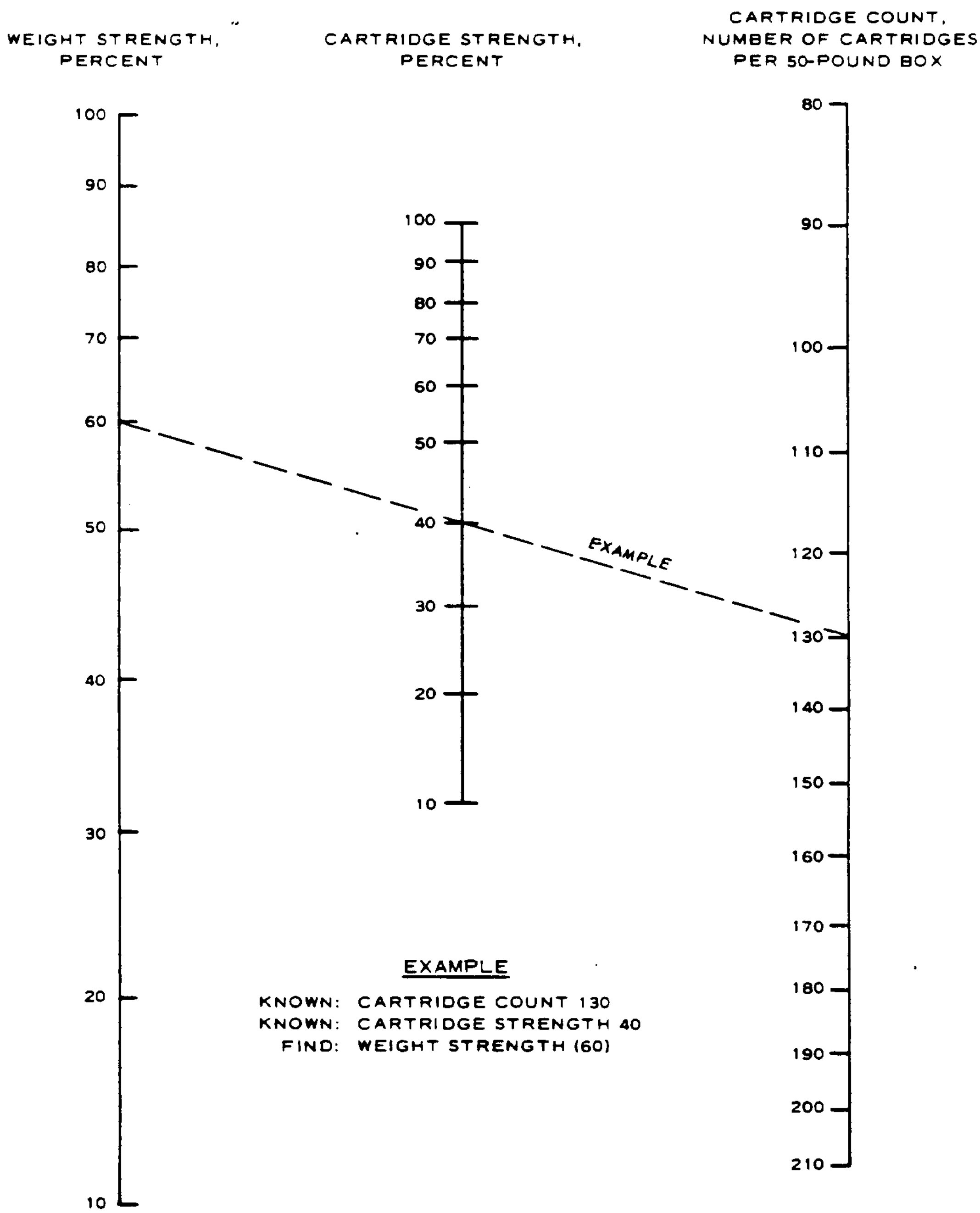

Fig. 3-2. Nomograph for comparing weight strength and cartridge strength[6]

(5) Usually dynamites are rated on weight strength and gelatins on cartridge strength. Commonly only a trade name or a coded designation is given, and the strength as well as the explosive type usually must be obtained from the manufacturer.

(6) These examples show that strength is not a good basis for rating explosives. Detonation pressure is a better indicator of an explosive's ability to perform work (see d below).

b. Detonation Velocity.

(1) The most important single property in rating an explosive is detonation velocity, which may be expressed for either confined or unconfined conditions. It is the speed at which the detonation wave travels through the explosive. Since explosives in boreholes are confined to some degree, the confined value is the more significant. Most manufacturers, however, measure the detonation velocity in an unconfined column of explosive 1-1/4 in. in diameter. The detonation velocity of an explosive is dependent on the density, ingredients (Fig. 3-3), particle size, charge diameter, and degree of confinement. Decreased particle size, increased charge diameter, and increased confinement all tend to increase the detonation velocity. Unconfined velocities are generally 70 to 80 percent of confined velocities.

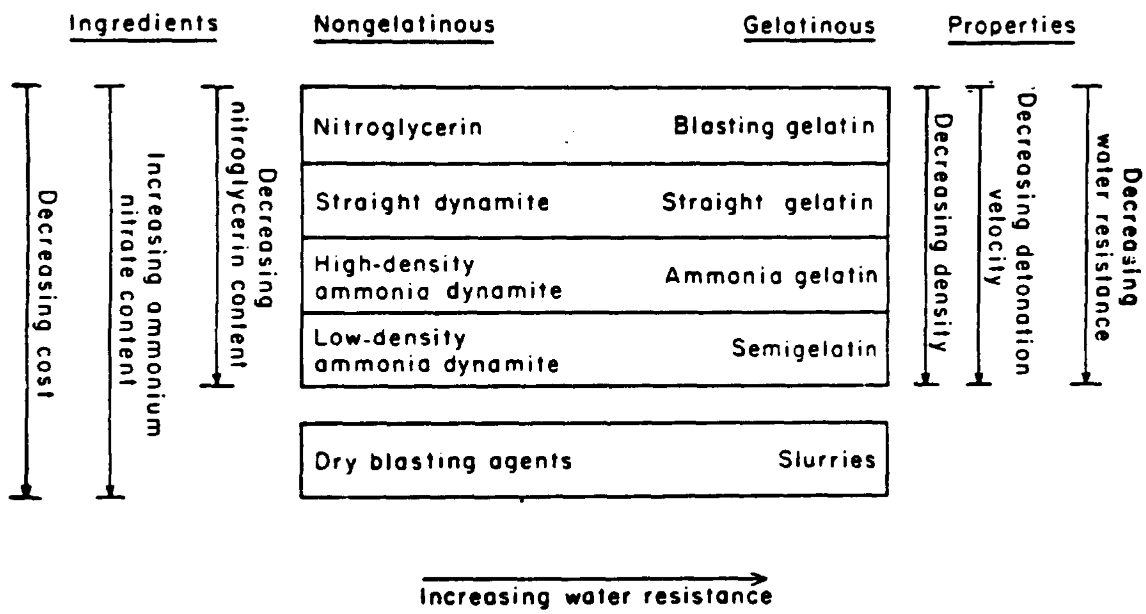

Fig. 3-3. Some relative properties and ingredients of commercial explosives[6]

(2) The confined detonation velocity of commercial explosives varies from 4,000 to 25,000 fps. With cartridged explosives the confined velocity is seldom attained. Some explosives and blasting agents (see para 3-6) are sensitive to diameter changes. As diameter is reduced, the velocity is reduced until at some critical diameter, propagation is no longer assured and misfires are likely.

c. Density and Specific Gravity. Densities of explosives are usually indicated in terms of specific gravity.

(1) The specific gravity of commercial explosives ranges from 0.6 to 1.7 with corresponding cartridge counts of 232 to 83. For bulk explosives, the pounds of explosive per foot of charge length in a given size borehole is often referred to as the charge concentration (or loading density).

(2) Denser explosives usually give higher detonation velocities and pressures. A dense explosive may be desirable for difficult blasting conditions or where fine fragmentation is required. Low-density explosives will suffice in easily fragmented or closely jointed rocks and are preferred for quarrying coarse material.

(3) The density of an explosive is important in wet conditions. An explosive with a specific gravity of less than 1.0 or a cartridge count greater than 140 will not sink in water.

d. Detonation Pressure.

(1) Detonation pressure, a function of the detonation velocity and density, is a measure of the pressure in the detonation wave. Since detonation pressure is not usually mentioned as a property of an explosive, it is not usually considered in the choice of an explosive. However, the amplitude of the stress pulse from an explosion in rock is related to the detonation pressure. The reflection of this stress pulse at a free face is an important mechanism in spalling. The relationship of detonation velocity and density to detonation pressure is somewhat complex but the following equation approximates it.[7]

$$P = 4.18 \times 10^{-7} \left(\frac{DC^2}{1 + 0.80D} \right)$$

where

P = detonation pressure, kilobars (1 kbar = 14,504 psi)

D = specific gravity

C = detonation velocity, fps

The nomograph in Fig. 3-4 can be used to find the detonation pressure of an explosive when the detonation velocity and specific gravity are known. The detonation pressure depends more on detonation velocity (see equation on page 3-5) than on specific gravity. A high detonation pressure is preferable for fragmenting hard, dense rock, such as granite, whereas in softer rock such as shale a lower pressure will be sufficient (Chapter 6). Detonation pressures of commercial explosives range from 10 kbar to over 140 kbar.

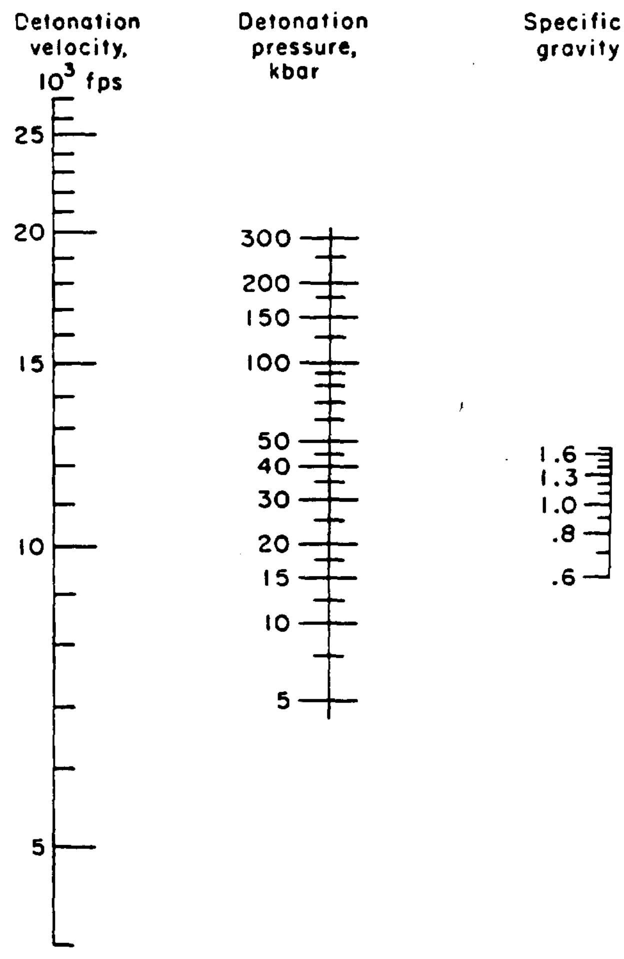

Fig. 3-4. Nomograph for finding detonation pressure[6]

(2) Fig. 3-5 shows the average confined velocity and specific gravity and calculated detonation pressure of explosives.

e. Water Resistance. The water resistance of an explosive is a measure of its ability to withstand exposure to water without deteriorating or losing sensitivity, where sensitivity is the ease with which an explosive will detonate. If water is standing in the blasthole, and the time between loading and firing is fairly short, an explosive with a water resistance rating of "Good" will be sufficient. If the exposure is prolonged or if the water is percolating through the borehole, "Very Good" to "Excellent" water resistance is required. In general, gelatins offer the best water resistance. Higher density dynamites have fair to good water resistance, whereas low-density dynamites have little or none. Emission of brown nitrogen oxide fumes from a blast often means that the explosive has deteriorated from exposure to water and indicates that a change should be made in the choice of explosive or grade.

f. Fume Class.

(1) Detonation of a commercial explosive produces water vapor, carbon dioxide, and nitrogen. Undesirable poisonous gases such as carbon monoxide and nitrogen oxides are usually formed also. These gases are known as fumes, and the fume class of an explosive indicates the nature and quantity of these undersirable gases formed in the detonation process. The ratings, listed in subsequent sections, are based on use underground. Fumes are seldom an important factor for open work.

(2) Removing a cartridged explosive from its cartridge will upset the oxygen balance and unfavorably affect the explosive's fume qualities and blasting efficiency. Water in the blasthole may also have an adverse effect on the fumes produced by a blast, either by causing deterioration of the explosive or by absorbing heat during detonation.

3-3. Ingredients of Explosives. Ingredients of high explosives are classified as explosive bases, combustibles, oxygen carriers, antacids, and absorbents (Table 3-1). Some ingredients perform more than one function. An explosive base is a solid or liquid which, upon the application of sufficient heat or shock, decomposes to gases with an accompanying release of considerable heat. A combustible combines with excess oxygen to prevent the formation of nitrogen oxides. An oxygen carrier assures complete oxidation of the carbon to prevent the formation of carbon monoxide. The formation of nitrogen oxides or carbon monoxide, in addition to being undesirable from the standpoint of fumes, results in lower heat of explosion and efficiency than when carbon dioxide and

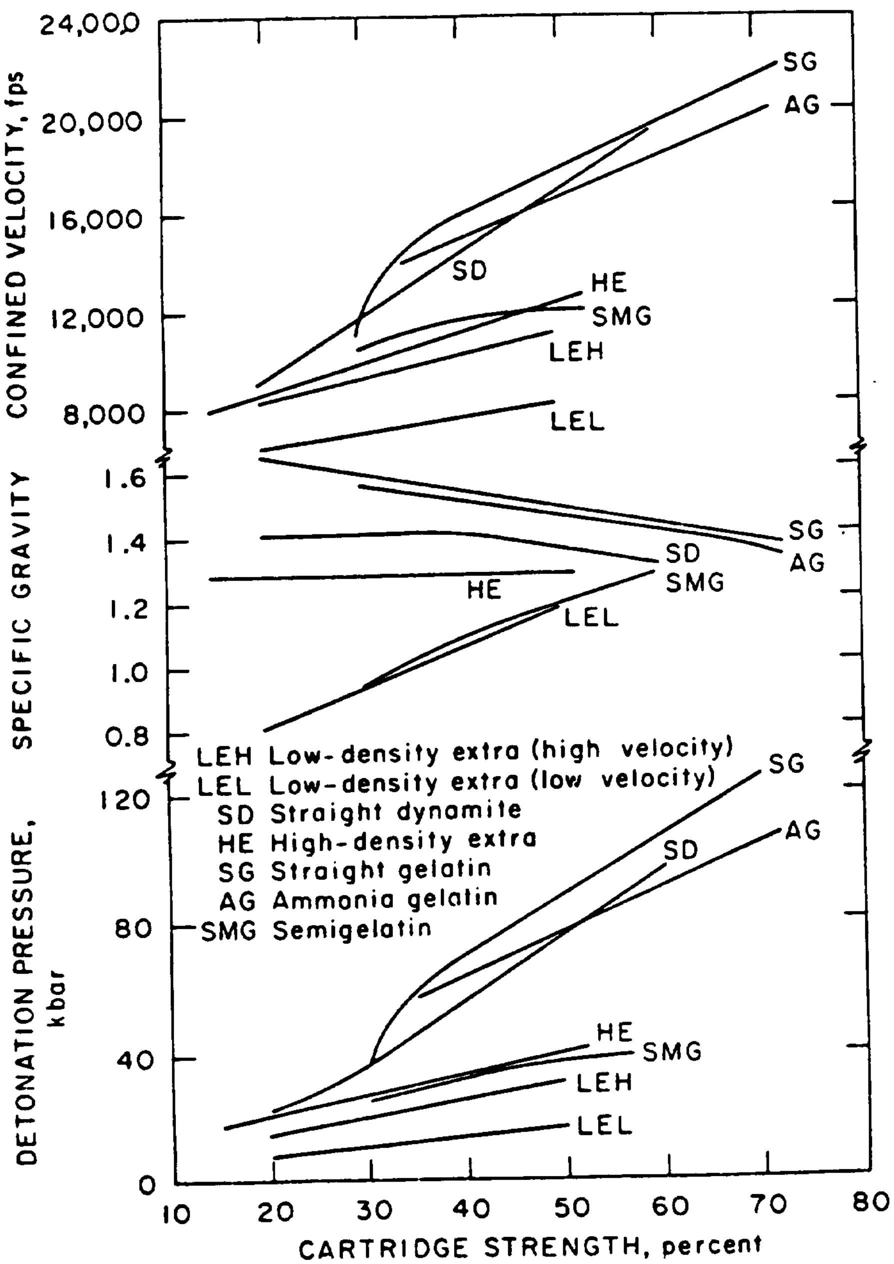

Fig. 3-5. Average confined velocity and specific gravity and calculated detonation pressure of explosives[6]

Table 3-1. Ingredients Used in Explosives

Ingredient	Chemical Formula	Function
Ethylene glycol dinitrate	$C_2H_4(NO_3)_2$	Explosive base; lowers freezing point
Nitrocellulose (guncotton)	$(C_6H_7(NO_3)_3O_2)n$	Explosive base; gelatinizing agent
Nitroglycerin	$C_3H_5(NO_3)_3$	Explosive base
Tetranitro-diglycerin	$C_6H_{10}N_4O_{13}$	Explosive base; lowers freezing point
Nitrostarch	---	Explosive base; "nonheadache" explosives
Organic nitrocompounds	---	Explosive base; lowers freezing point
Trinitrotoluene (TNT)	$C_7H_5N_3O_6$	Explosive base
Metallic powder	Al	Fuel-sensitizer; used in high-density slurries
Black powder	$NaNO_3$+C+S	Explosive base; deflagrates
Pentaerythritol tetranitrate (PETN)	$C_5H_8N_4O_{12}$	Explosive base; caps, detonating fuse
Lead azide	$Pb(N_3)_2$	Explosive base; used in blasting caps
Mercury fulminate	$Hg(ONC)_2$	Explosive base; formerly used in blasting caps
Ammonium nitrate	NH_4NO_3	Explosive base; oxygen carrier
Liquid oxygen	O_2	Oxygen carrier
Sodium nitrate	$NaNO_3$	Oxygen carrier
Potassium nitrate	KNO_3	Oxygen carrier
Ground coal	C	Combustible
Charcoal	C	Combustible
Paraffin	C_nH_{2n+2}	Combustible
Sulfur	S	Combustible
Fuel oil	$(CH_3)_2(CH_2)_n$	Combustible
Wood pulp	$(C_6H_{10}O_5)_n$	Combustible; absorbent
Lampblack	C	Combustible
Kieselguhr	SiO_2	Absorbent; prevents caking
Chalk	$CaCO_3$	Antacid
Calcium carbonate	$CaCO_3$	Antacid
Zinc oxide	ZnO	Antacid
Sodium chloride	NaCl	Flame depressant (permissible explosives)

nitrogen are formed. Antacids increase stability in storage, and absorbents absorb liquid explosive bases.

3-4. Dynamites. The properties and compositions of the various types of dynamites are summarized in Tables 3-2 and 3-3, respectively. Each type is discussed in detail below.

a. Straight Nitroglycerin Dynamite.

(1) Dynamite was originally a mixture of nitroglycerin and diatomite, a porous, inert silica. Today, straight nitroglycerin dynamite consists of nitroglycerin, with sodium nitrate, antacid, carbonaceous fuel, and sometimes sulfur in place of the inert filler. It is most commonly manufactured in weight strengths of 20 to 60 percent. Because of the tendency of nitroglycerin to freeze at low working temperature, another explosive oil usually replaces part of the nitroglycerin in a straight dynamite.

(2) Straight dynamite has a high detonation velocity which gives a shattering action. It resists water well in the higher grades but poorly in the lower grades. Straight dynamite generally has poor fume qualities, and is unsuitable for use underground or in poorly ventilated spaces. The use of straight dynamite has declined because of high cost, sensitivity to shock and friction, and high flammability. Ammonia ("extra") dynamites have replaced straight dynamite in most applications.

(3) Ditching dynamite is a name given to 50 percent straight dynamite. Its high sensitivity is advantageous in ditching where sympathetic detonation eliminates the need for caps or detonating fuse with individual charges. Sixty percent straight dynamite is sometimes packaged in special cartridges for underwater work.

b. High-Density Ammonia (Extra) Dynamite.

(1) Ammonia dynamites (extra dynamite) are the most widely used cartridged explosives. An ammonia dynamite is similar to a straight dynamite except that ammonium nitrate replaces a portion of the nitroglycerin and sodium nitrate.

(2) High-density ammonia dynamite is commonly manufactured in weight strengths of 20 to 60 percent. It is generally lower in detonation velocity, less dense, better in fume qualities, and considerably less sensitive to shock and friction than straight dynamite. Extra dynamite can be used effectively where the rock is not extremely hard and water conditions are not severe. It is widely used in quarrying, stripping, and

Table 3-2. Properties[1] of Dynamites

Weight Strength %	Cartridge Strength %	Specific Gravity	Confined Velocity fps	Water Resistance	Fume Class	Cartridge Count
Straight Nitroglycerin Dynamite						
60	60	1.3	19,000	Good	Poor	106
50	50	1.4	17,000	Fair	Poor	104
40	40	1.4	14,000	Fair	Poor	100
30	30	1.4	11,500	Poor	Poor	100
20	20	1.4	9,000	Poor	Poor	100
High-Density Ammonia Dynamite						
60	52	1.3	12,500	Fair	Good	110
50	45	1.3	11,500	Fair	Good	110
40	35	1.3	10,500	Fair	Good	110
30	25	1.3	9,000	Fair	Good	110
20	15	1.3	8,000	Fair	Good	110
Low-Density Ammonia Dynamite, High-Velocity Series						
65	50	1.2	11,000	Fair	Fair	120
65	45	1.1	10,400	Fair	Fair	129
65	40	1.0	10,000	Fair	Fair	135
65	35	1.0	9,800	Fair	Fair	141
65	30	0.9	9,400	Poor	Fair	153
65	25	0.9	8,800	Poor	Fair	163
65	20	0.8	8,300	Poor	Fair	174
Low-Density Ammonia Dynamite, Low-Velocity Series						
65	50	1.2	8,100	Fair	Fair	120
65	45	1.1	7,800	Poor	Fair	129
65	40	1.0	7,500	Poor	Fair	135
65	35	1.0	7,200	Poor	Fair	141
65	30	0.9	6,900	Poor	Fair	153
65	25	0.9	6,500	Poor	Fair	163
65	20	0.8	6,300	Poor	Fair	174

Note: Values shown are the averages of several manufacturers.

(1) Specific gravity and confined detonation velocity can be used to calculate characteristic impedance which is useful in choosing the explosive for a given rock as explained in paragraph 6-2.

Table 3-3. Composition[1] of Dynamites

Component	Weight Strength 20%	30%	40%	50%	60%	100%
	Straight Nitroglycerin Dynamite					
Nitroglycerin	20.2	29.0	39.0	49.0	56.8	--
Sodium nitrate	59.3	53.3	45.5	34.4	22.6	--
Carbonaceous fuel	15.4	13.7	13.8	14.6	18.2	--
Sulfur	2.9	2.0	--	--	--	--
Antacid	1.3	1.0	0.8	1.1	1.2	--
Moisture	0.9	1.0	0.9	0.9	1.2	--
	High-Density Ammonia Dynamite					
Nitroglycerin	12.0	12.6	16.5	16.7	22.5	--
Sodium nitrate	57.3	46.2	37.5	25.1	15.2	--
Ammonium nitrate	11.8	25.1	31.4	43.1	50.3	--
Carbonaceous fuel	10.2	8.8	9.2	10.0	8.6	--
Sulfur	6.7	5.4	3.6	3.4	1.6	--
Antacid	1.2	1.1	1.1	0.8	1.1	--
Moisture	0.8	0.8	0.7	0.9	0.7	--

(1) Values shown are in percent by weight and are the averages of several manufacturers.

in well-ventilated mines for smaller diameter holes of small blasting operations.

c. Low-Density Ammonia (Extra) Dynamite.

(1) Low-density ammonia dynamite has a weight strength of approximately 65 percent and a cartridge strength from 20 to 50 percent. Like a high-density extra dynamite, it contains a low proportion of nitroglycerin and a high proportion of ammonium nitrate. The different cartridge strengths are obtained by varying the density and grain size of the ingredients.

(2) Several manufacturers produce two series of low-density ammonia dynamite, a high- and a low-velocity series. Both series are of lower velocity and density than high-density extra dynamite. Because of its slow, heaving action, the low-velocity series is well suited to blasting soft material such as clay-shale or where a coarse product such as riprap is desired. It is well suited for use in structural

excavation blasting in certain rock types.

(3) Fume qualities and water resistance vary with the cartridge material. Wrappers sprayed with paraffin give fair to poor water resistance and fair fume rating, whereas a paraffin-impregnated wrapper gives very poor water resistance and a better fume rating. The explosive has little more water resistance than that provided by the wrapper. Low-density extra is the lowest cost cartridged explosive available.

(4) The composition of low-density ammonia dynamites is similar to that of a 60 percent high-density extra dynamite with a lower proportion of nitroglycerin and a higher proportion of ammonium nitrate. Table 3-2 lists the properties of the high- and low-velocity series, with paraffin-sprayed cartridge.

3-5. Gelatins. The properties and compositions of the various types of gelatins are summarized in Tables 3-4 and 3-5, respectively. Each type is discussed in detail below.

a. Blasting Gelatin. Blasting gelatin is a rubber-textured explosive made by adding nitrocellulose (guncotton) to nitroglycerin. An antacid is added for stability in storage. Wood meal is usually added to improve sensitivity, although this is not indicated in Table 3-5. Blasting gelatin attains a very high detonation velocity and has excellent water resistance, but it emits large volumes of noxious fumes upon detonation. It is the most powerful of all commercial explosives. Blasting gelatin is also known as "oil well explosive."

b. Straight Gelatin.

(1) Straight gelatin is a dense, plastic explosive consisting of nitroglycerin or other explosive oil gelatinized with nitrocellulose, an antacid, sodium nitrate, carbonaceous fuel, and sometimes sulfur. Since the gelatin tends to coat the other ingredients, straight gelatin is waterproof. Straight gelatin is the equivalent of straight dynamite in the dynamite category and is manufactured in weight strengths of 20 to 90 percent with corresponding cartridge strengths of 30 to 80 percent. The cartridge strength or the weight strength may be referred to by the manufacturer as the "grade" of the gelatin, a term which is confusing. Straight gelatin has been used in very hard rock or as a bottom charge in a column of explosives. It has been replaced in most applications by a more economical substitute such as ammonia gelatin, but higher grades are still used in underwater blasting and in deep well shooting.

(2) Straight gelatin has two characteristic detonation velocities,

Table 3-4. Properties[1] of Gelatins

Weight Strength %	Cartridge Strength %	Specific Gravity	Confined Velocity fps	Water Resistance	Fume Class	Cartridge Count
			Blasting Gelatin			
100	90	1.3	25,000-26,000	Excellent	Poor	110
			Straight Gelatin			
90	80	1.3	23,000	Excellent	Poor	105
70	70	1.4	21,000	Excellent	Poor	101
60	60	1.4	20,000	Excellent	Good	98
50	55	1.5	18,500	Excellent	Good	95
40	45	1.5	16,500	Excellent	Good	92
30	35	1.6	14,500	Excellent	Good	88
20	30	1.7	11,000	Excellent	Good	85
			Ammonia Gelatin			
80	72	1.3	20,000	Excellent	Good	106
70	67	1.4	19,000	Excellent	Very good	102
60	60	1.4	17,500	Excellent	Very good	100
50	52	1.5	16,500	Excellent	Very good	97
40	45	1.5	16,000	Excellent	Very good	92
30	35	1.6	14,000	Excellent	Very good	90
			Semigelatin			
63	60	1.3	12,000	Very good	Very good	110
63	50	1.2	12,000	Very good	Very good	118
63	40	1.1	11,500	Good	Very good	130
63	30	0.9	10,500	Fair	Very good	150

Note: Values shown are the averages of several manufacturers.

(1) Specific gravity and confined detonation velocity can be used to calculate characteristic impedance which is useful in choosing the explosive for a given rock as explained in paragraph 6-2.

Table 3-5. Composition[1] of Gelatins

Component	Weight Strength 20%	30%	40%	50%	60%	100%
			Blasting Gelatin			
Nitroglycerin	--	--	--	--	--	91.0
Nitrocellulose	--	--	--	--	--	7.9
Antacid	--	--	--	--	--	0.9
Moisture	--	--	--	--	--	0.2
			Straight Gelatin			
Nitroglycerin	20.2	25.4	32.0	40.1	49.6	--
Sodium nitrate	60.3	56.4	51.8	45.6	38.9	--
Nitrocellulose	0.4	0.5	0.7	0.8	1.2	--
Carbonaceous fuel	8.5	9.4	11.2	10.0	8.3	--
Sulfur	8.2	6.1	2.2	1.3	--	--
Antacid	1.5	1.2	1.2	1.2	1.1	--
Moisture	0.9	1.0	0.9	1.0	0.9	--
			Ammonia Gelatin			
Nitroglycerin	--	22.9	26.2	29.9	35.3	--
Nitrocellulose	--	0.3	0.4	0.4	0.7	--
Sodium nitrate	--	54.9	49.6	43.0	33.5	--
Ammonium nitrate	--	4.2	8.0	13.0	20.1	--
Carbonaceous fuel	--	8.3	8.0	8.0	7.9	--
Sulfur	--	7.2	5.6	3.4	--	--
Antacid	--	0.7	0.8	0.7	0.8	--
Moisture	--	1.5	1.4	1.6	1.7	--

(1) Values shown are in percent by weight and are the averages of several manufacturers.

the confined velocity and a much lower velocity which results from insufficient confinement, insufficient initiation, or high hydrostatic pressure. Extremely high water pressures may cause a misfire. To overcome this disadvantage, high-velocity gelatin has been developed. High-velocity gelatin is very similar to straight gelatin except that it is slightly less dense, more sensitive to detonation, and always detonates near its rated velocity regardless of water pressure or degree of confinement. High-velocity gelatin is particularly useful as a seismic explosive, and is also used in deep well and underwater work.

c. Ammonia Gelatin. Ammonia gelatin (special gelatin or gelatin extra) has a portion of the nitroglycerin and sodium nitrate replaced by ammonium nitrate. Ammonia gelatin is comparable to a straight gelatin in the same way that a high-density ammonia dynamite is comparable to a straight dynamite, and was developed as a cheaper substitute. Ammonia gelatin is commonly manufactured in weight strengths of 30 to 80 percent with corresponding cartridge strengths of 35 to 72 percent. Compared with straight gelatin, ammonia gelatin has a somewhat lower detonation velocity, better fume qualities, and less water resistance, although it will fire efficiently even after standing in water for several days. It is suitable for underground work because of its good fume rating. The higher strengths (70 percent or higher) are efficient as primers (para 3-8c) for blasting agents.

d. Semigelatin. A semigelatin is comparable to an ammonia gelatin as a low-density ammonia dynamite is comparable to a high-density ammonia dynamite. Like low-density extras, semigelatin has a uniform weight strength (60 to 65 percent) with the cartridge strength varying with the density and grain size of the ingredients. Its properties fall between those of high-density ammonia dynamite and ammonia gelatin, and it has great versatility. Semigelatin can be used to replace ammonia dynamite when more water resistance is needed. It is cheaper for wet work than ammonia gelatin, although its water resistance is not quite as high as that of ammonia gelatin. Semigelatin has a confined detonation velocity of 10,000 to 12,000 fps, which, in contrast to that of most explosives, is not seriously affected by lack of confinement. Very good fume qualities permit its use underground. The compositions are similar to ammonia gelatin with less nitroglycerin and sodium nitrate and more ammonium nitrate.

3-6. Blasting Agents (Nitrocarbonitrates). Blasting agents consist of mixtures of fuels and oxidizers, none of which are classified as explosive, which cannot be detonated by a No. 8 test blasting cap as packaged for shipment. Nitrocarbonitrate is a classification given to a blasting agent under the U. S. Department of Transportation regulations on packaging and shipping. A blasting agent consists of inorganic nitrates and carbonaceous fuels and may contain additional nonexplosive substances such as powdered aluminum or ferrosilicon to increase density. The addition of an explosive ingredient such as TNT (para 3-7a) changes the classification from a blasting agent to an explosive. Blasting agents may be dry or in slurry forms. Because of their insensitivity, blasting agents should be detonated by a primer (para 3-8) of high explosive. Ammonium nitrate-fuel oil (ANFO) has largely replaced dynamites and gelatins in bench blasting. Denser slurry blasting agents are supplanting dynamite and gelatin and dry blasting agents.

a. Dry Blasting Agents.

(1) The most widely used dry blasting agent is a mixture of ammonium nitrate prills (porous grains) and fuel oil. A properly balanced ANFO mixture detonates as follows:

$$3NH_4NO_3 + CH_2 \rightarrow 7H_2O + CO_2 + 3N_2$$

The fuel oil is not precisely CH_2, but this is sufficiently accurate to characterize the reaction. The right side of the equation contains only the desirable gases of detonation, although some CO and NO_2 are always formed. Weight proportions of ingredients for the equation are 94.5 percent ammonium nitrate and 5.5 percent fuel oil. In actual practice the proportions are 94 percent and 6 percent to assure an efficient chemical reaction of the nitrate.

(2) Uniform mixing of oil and ammonium nitrate is essential to development of full explosive force. Some blasting agents are premixed and packaged by the manufacturer. Where not premixed, several methods of mixing in the field can be employed to achieve uniformity. The best method, although not always the most practical one, is by mechanical mixer. A more common and almost as effective method of mixing is by uniformly soaking prills in opened bags with 8 to 10 percent of their weight of oil. After draining for at least a half hour the prills will have retained about the correct amount of fuel oil.

(3) Fuel oil can also be poured onto the ammonium nitrate in approximately the correct proportions as it is poured into the blasthole. For this purpose, about 1 gal of fuel oil for each 100 lb of ammonium nitrate will equal approximately 6 percent by weight of oil. The oil can be added after each bag or two of prills, and it will disperse relatively rapidly and uniformly.

(4) Inadequate priming imparts a low initial detonation velocity to a blasting agent, and the reaction may die out and cause a misfire. High explosive boosters are sometimes spaced along the borehole to assure propagation throughout the column. In charge diameters of 6 in. or more, dry blasting agents attain confined detonation velocities of more than 12,000 fps, but in a diameter of 1-1/2 in., the velocity is reduced to 60 percent (Table 3-6).

(5) Advantages of insensitive dry blasting agents are their safety, ease of loading, and low price. In the free-flowing form, they have a great advantage over cartridged explosives because they completely fill

Table 3-6. Confined Detonation Velocity and Charge Concentration of ANFO

Borehole Diameter in.	Confined Velocity[1] fps	Charge Concentration lb/ft of Borehole
1-1/2	7,000- 9,000	0.6- 0.7
2	8,500- 9,900	1.1- 1.3
3	10,000-10,800	2.5- 3.0
4	11,000-11,800	4.4- 5.2
5	11,500-12,500	6.9- 8.2
6	12,000-12,800	9.9-11.7
7	12,300-13,100	13.3-15.8
8	12,500-13,300	17.6-20.8
9	12,800-13,500	22.0-26.8
10	13,000-13,500	27.2-32.6
11	13,200-13,500	33.0-39.4
12	13,300-13,500	39.6-46.8

(1) Confined detonation velocity can be used to calculate characteristic impedance which is useful in choosing the explosive for a given rock as explained in paragraph 6-2.

the borehole. This direct coupling to the walls assures efficient use of explosive energy. Ammonium nitrate is water soluble so that in wet holes, some blasters pump the water from the hole, insert a plastic sleeve, and load the blasting agent into the sleeve. Special precautions should be taken to avoid a possible building up of static electrical charge, particularly when loading pneumatically. When properly oxygen-balanced, the fume qualities of dry blasting agents permit their use underground. Canned blasting agents, once widely used, have unlimited water resistance, but lack advantages of loading ease and direct coupling to the borehole.

(6) The specific gravity of ANFO varies from 0.75 to 0.95 depending on the particle density and sizes. Table 3-6 shows how confined detonation velocity and charge concentration of ANFO vary with borehole diameter. Pneumatic loading results in high detonation velocities and higher charge concentrations, particularly in holes smaller than 3 in. (otherwise such small holes are not usually recommended for ANFO blasting).

b. Slurries.

(1) Slurries, sometimes called water gels, contain ammonium

nitrate partly in aqueous solution. Depending on the remainder of the ingredients, slurries can be classified as either blasting agents or explosives. Slurry blasting agents contain nonexplosive sensitizers or fuels such as carbon, sulfur, or aluminum, and are not cap sensitive; whereas slurry explosives contain cap-sensitive ingredients such as TNT and the mixture itself may be cap sensitive. Slurries are thickened and gelled with a gum, such as guar gum, to give considerable water resistance.

(2) Since most slurries are not cap sensitive, all slurries, even those containing TNT, are often grouped under the term blasting agent. This grouping is incorrect. A blasting agent, as defined by the National Fire Protection Association, shall contain no ingredient that is classified as an explosive.

(3) Slurry blasting agents require adequate priming with a high-velocity explosive to attain proper detonation velocities, and often require boosters of high explosive spaced along the borehole to assure complete detonation. Slurry explosives may or may not require priming. The detonation velocities of slurries, between 12,000 and 18,000 fps, vary with ingredients used, charge diameter, degree of confinement, and density. The detonation velocity of a slurry, however, is not as dependent on charge diameter as that of a dry blasting agent. The specific gravity varies from 1.1 to 1.6. The consistency of most slurries ranges from fluid near 100° F to rigid at freezing temperatures, although some slurries maintain their fluidity even at freezing temperatures. Slurries consequently give the same advantageous direct borehole coupling as dry blasting agents as well as a higher detonation velocity and a higher density. Thus, more energy can be loaded into a given volume of borehole. Saving in costs realized by drilling smaller holes or using larger burden and spacing (see definitions in para 5-2a) will often more than offset the higher cost per pound of explosive. Adding powdered aluminum as a sensitizer to slurries greatly increases the heat of explosion or the energy release. Aluminized slurries have been used in extremely hard rock with excellent results.

(4) A slurry and a dry blasting agent may be used in the same borehole in "slurry boosting," with the bulk of the charge being dry blasting agent. Boosters placed at regular intervals may improve fragmentation. In another application of slurry boosting, the slurry is placed in a position where fragmentation is difficult, such as a hard toe or a zone of hard rock in the burden. The combination will often give better overall economy than straight slurry or dry blasting agent.

3-7. Other Explosives.

a. TNT. Trinitrotoluene, $C_7H_5N_3O_6$ (TNT), is a stable, cap-sensitive compound (not extremely sensitive) that has excellent water resistance. Cast TNT has a specific gravity of 1.56 and a confined detonation velocity of about 22,000 fps, and is used as a primer and booster for blasting agents. It is also used in the pelletized form where a free-running explosive with high density and good water resistance is needed. One of the principal uses of TNT at present is as a sensitizer for slurries.

b. PETN. Pentaerythritol tetranitrate, $C_5H_8N_4O_{12}$ (PETN), has a specific gravity of solids of 1.76 and a confined detonation velocity of over 25,000 fps. PETN is used as a priming composition in detonators, a base charge in blasting caps, and a core load for detonating fuse (para 3-8b).

c. Pentolite. Pentolite is a mixture of equal parts of TNT and PETN. When cast, it has a specific gravity of 1.65 and a confined detonation velocity of 24,000 to 25,000 fps. Cast pentolite is used as a primer and booster for blasting agents where its high detonation pressure assures efficient initiation of the blasting agent.

d. RDX. Cyclotrimethylenetrinitramine, $C_3H_6N_6O_6$ (RDX), is second in strength to nitroglycerin among common explosive substances. When compressed to a specific gravity of 1.70, it has a confined detonation velocity of about 27,000 fps. RDX is the primary ingredient in the explosive mixtures C-3, C-4, and Composition B. RDX is used as the base charge for some detonators.

e. Composition B. Composition B is a mixture of RDX and TNT with about 1 percent wax added. Cast Composition B has a specific gravity of 1.65 and a detonation velocity of about 25,000 fps and is used as a primer and booster for blasting agents.

f. Permissible Explosives. A permissible explosive is one designed for use where explosive gases and dusts may be encountered such as in coal mines. They must be properly oxygen-balanced to pass the test for poisonous fumes. Sodium chloride or some other flame depressant is usually added to the explosive to lower its heat of explosion and minimize the chance of ignition of gas or coal dust.

g. Black Powder. On CE projects the use of black powder (for composition, see Table 3-1) is prohibited except specially formulated black powders, commonly containing additional inert ingredients, used as the core load of safety fuse. These powders are finely ground and compacted sufficiently to give a prescribed rate of burning.

3-8. Detonators and Primers.

a. Blasting Caps.

(1) Electric blasting caps, the most commonly used initiating device, may be inserted directly into the explosive cartridge or used with detonating fuse (Fig. 3-6). An electric blasting cap consists of two insulated leg wires inserted in an insulated metal capsule and connected by a thin-filament bridge wire. When sufficient current is applied through the leg wires, the bridge wire gives off heat energy and ignites a flash charge of heat-sensitive explosive. The explosion of the flash charge detonates a primer charge, which in turn detonates a base charge of powerful explosive such as PETN or RDX. In some caps the flash and primer charges are combined. The base charge of the cap detonates with sufficient force to initiate a cap-sensitive explosive or detonating fuse.

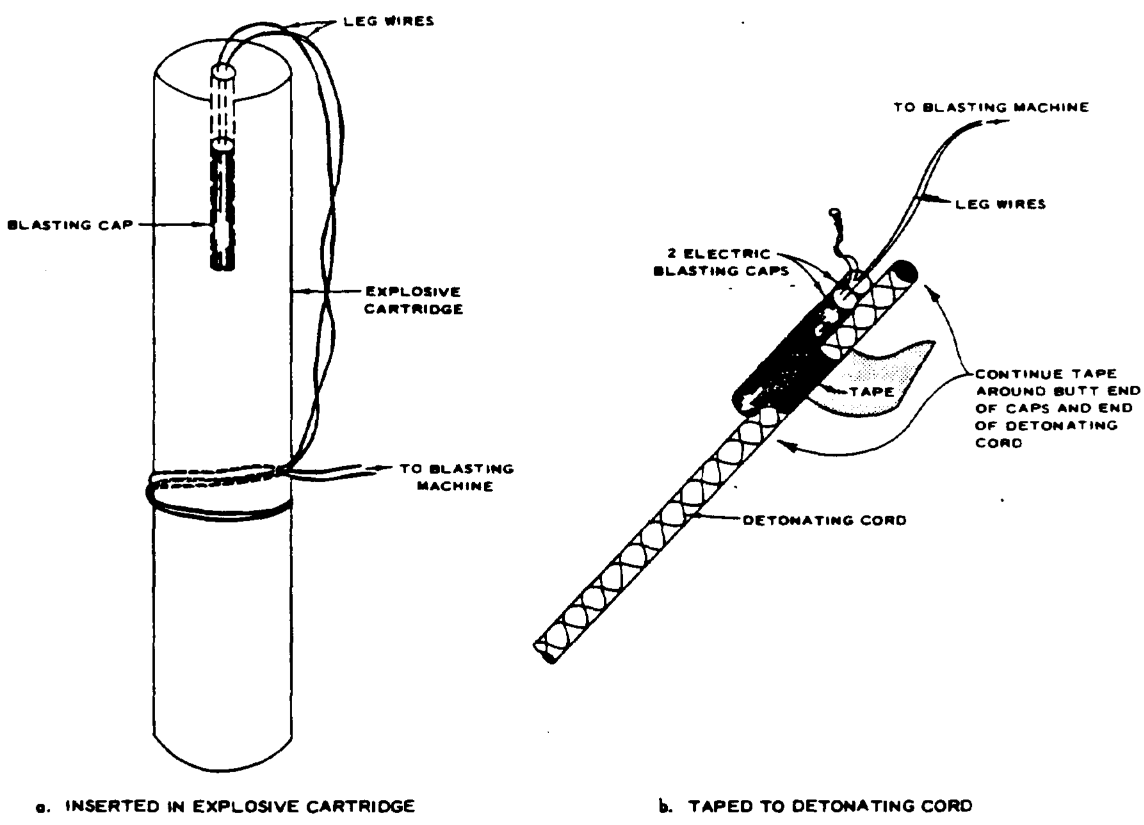

Fig. 3-6. Application of blasting caps (in part from Du Pont[8])

(2) Advantages of electric blasting caps include safety in handling, variety of delay periods available, and choice of exact time of detonation. Noise and potential public relations problems are reduced by initiating the charge in the borehole with a blasting cap instead of using trunk lines and down lines of detonating fuse. Care should be used to avoid stray, induced electric currents or those caused by lightning or radio frequency energy (see para 1-3). Manufacturer's data should be consulted for current requirements. Because of variation from brand to brand, mixing brands of caps in a round should not be done.

(3) A delay element of explosive is placed between the bridge wire and the primer charge in a delay electric cap. The delay element is accurately calibrated to give a specified time lapse between the application of electric current and the detonation. Two series of delays are available: short or millisecond delays, with delay increments of 25 msec in the lower range and 50 msec in the upper range; and longer delays, often called slow delays, with delay increments of 0.5 and 1 sec. Where maximum fragmentation is desired, millisecond delays are used to produce good breakage and reduce airblast and ground vibrations. Slow delays are primarily used underground where they provide time for rock movement between delays. Longer delays are likely to result in coarser fragmentation than that obtained with millisecond delays.

(4) The cap and fuse is another system of initiating explosives. A fuse cap is a small tube, closed at one end, which contains a heat-sensitive primer charge plus a base charge such as PETN. The cap has an open space above the primer charge into which the safety fuse is inserted (Fig. 3-7). The safety fuse consists of a core of potassium nitrate black powder enclosed in a covering of textile and waterproofing compound. The several types of fuses vary in water resistance and flexibility. Most burn at 40 seconds per foot (spf), but some burn at 30 spf. The safety fuse is butted to the charge in the cap and crimped to form a tight bond. Cap and fuse systems, used primarily underground where rotational firing is necessary, can give an unlimited number of slow delay intervals. The caps are more dangerous to handle than electric caps because the highly sensitive explosive charge is exposed. Mishandling of the fuse can cause a change in the burning rate. High degree of confinement increases the burning rate; high altitude decreases the burning rate. Rates should always be determined at the site.

b. Detonating Fuse.

(1) A detonating fuse, also called detonating cord, consists of a core of high explosive, usually PETN, within a waterproof plastic sheath enclosed in a reinforcing cover. Reinforcing covers come in a variety

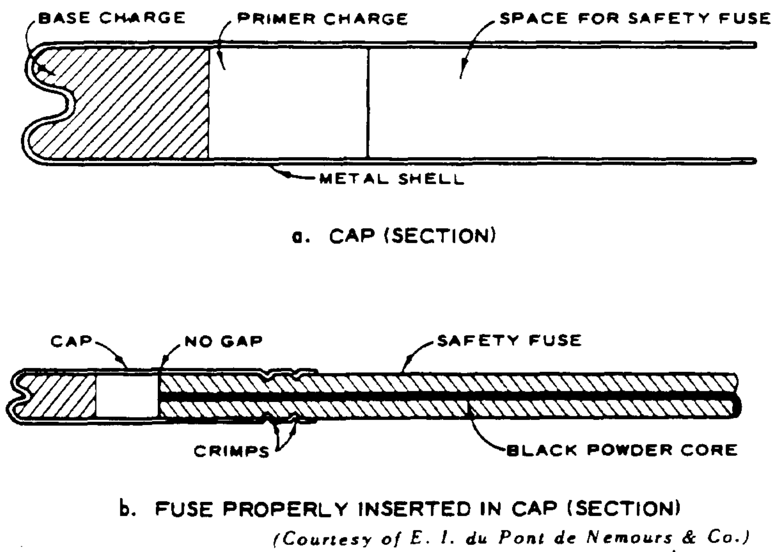

Fig. 3-7. Safety fuse and cap (modified from Du Pont[8])

of types and tensile strengths suitable for different blasting conditions. Detonating fuses with core loadings ranging from 1 to 400 grains per foot (gr/ft) of PETN are available with 25- and 50-gr/ft loads most commonly used. All grades can be detonated with a blasting cap and have a detonation velocity of approximately 21,000 fps.

(2) The marked insensitivity to external shock and friction makes a detonating fuse ideal for both down lines and trunk lines for primary blasting. Since the blasting cap need not be connected into the circuit until just prior to the time of firing, most of the hazard of premature detonation is eliminated. Detonating fuses with loads of 25 or 50 gr/ft will detonate any cap-sensitive explosive and are very useful when blasting with deck charges (para 5-2c) or when using multiple boosters with blasting agents. A detonating fuse with a core loading of 50 gr/ft will not detonate a blasting agent.

(3) Detonating fuses have wide application in underwater work, but the ends of the detonating fuse should be protected from water. PETN will slowly absorb water and as a result become insensitive to initiation. Even when damp, however, a detonating fuse will detonate if initiated on a dry end.

(4) Millisecond delay connectors are available for use with detonating fuses. Each connector consists of a delay element with a length of detonating fuse connected to each end. The connectors are tied

between two ends of the detonating fuse in the trunk line and permit the use of an unlimited number of delay periods (Fig. 3-8). Delay connectors are commonly available in periods of 5, 9, and 17 msec.

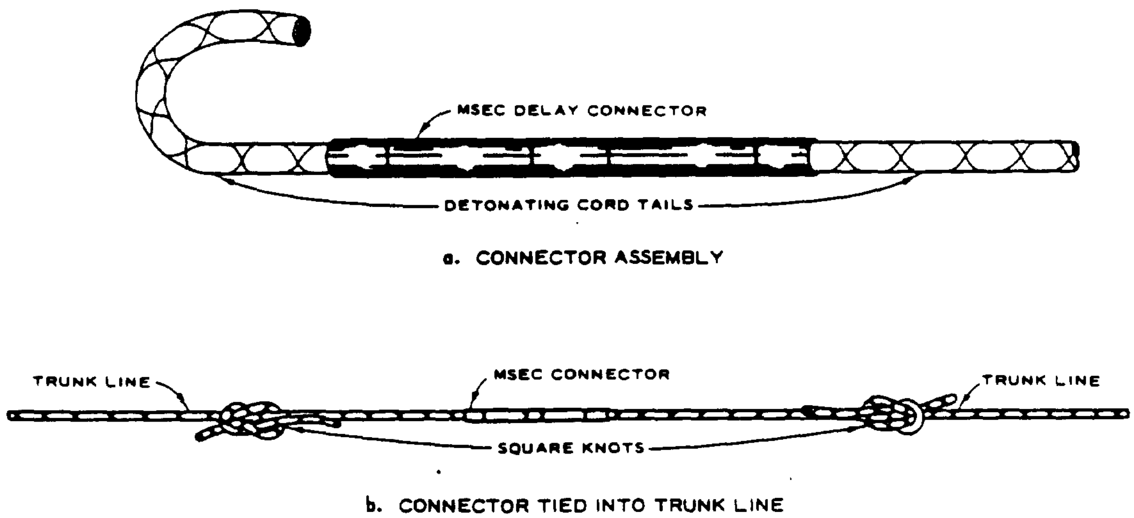

Fig. 3-8. Millisecond delay connectors

(5) A detonating fuse with a core load of 1 to 5 gr/ft of PETN, known as low-energy detonating cord (LEDC), has two principal uses. The first is where airblast from a trunk line presents a problem. LEDC produces virtually no airblast. The second use is as a down line where center or bottom initiation is desired. Since LEDC will not detonate commercial cap-sensitive explosives, it must be used in conjunction with special connectors and blasting caps. This system requires the exercise of extreme care to prevent misfires.

c. Primers and Boosters.

(1) A primer is a cartridge of explosive used in conjunction with a cap or detonating fuse to initiate the detonation of a blasting agent. Primers are necessary in using blasting agents in order to attain high detonation pressure and temperature rapidly and thereby to increase efficiency of the main detonation. Three characteristics of an efficient primer are high detonation pressure, adequate size, and high detonation velocity. High velocity, high strength dynamite is commonly used.

(2) A booster has no cap or fuse and merely assures propagation of the detonation.